End-use Load Profiles for the U.S. Building Stock

Technical Advisory Group Meeting #5
December 17, 2019

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Logistics

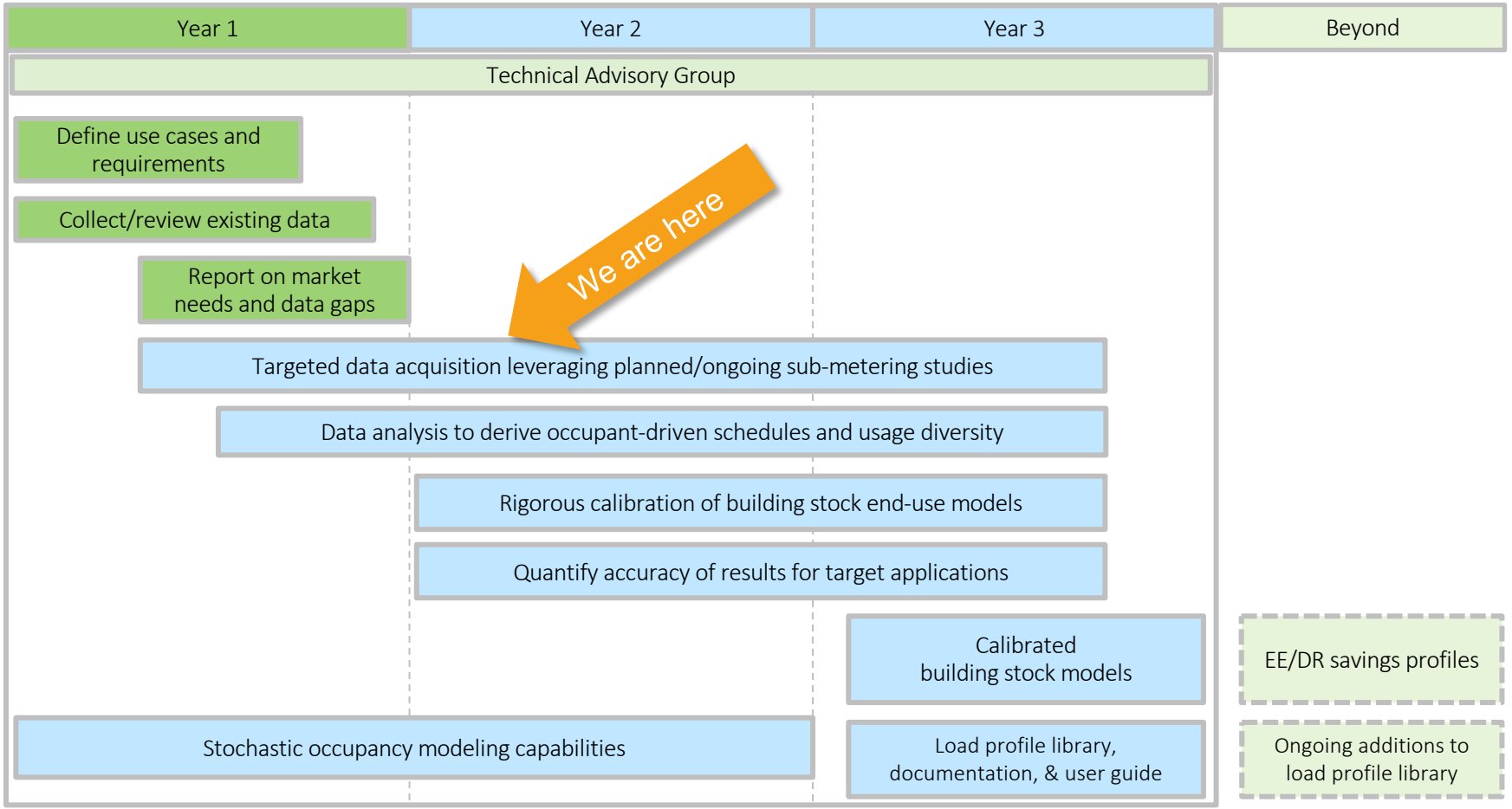
- Welcome back!
- Because of the large number of participants on the phone, everyone is in listen-only mode during presentations.
- Please use the chat box to send us clarifying questions during presentations. We will unmute lines after each topic for open dialogue.
- Slides will be available after the webinar on the project website https://www.nrel.gov/buildings/end-use-load-profiles.html

Agenda

- Project updates
- Progress updates
  - Calibration data procurement
  - Residential calibration progress
    - Initial comparison to EIA and load research data [unmute for discussion]
    - Residential end use transferability [unmute for discussion]
  - Uncertainty quantification framework
    - Selection of quantities of interest (QOIs)
  - Occupancy modeling
    - Commercial
    - Residential
- Conclusion & Next Steps [unmute for discussion]

Project Updates

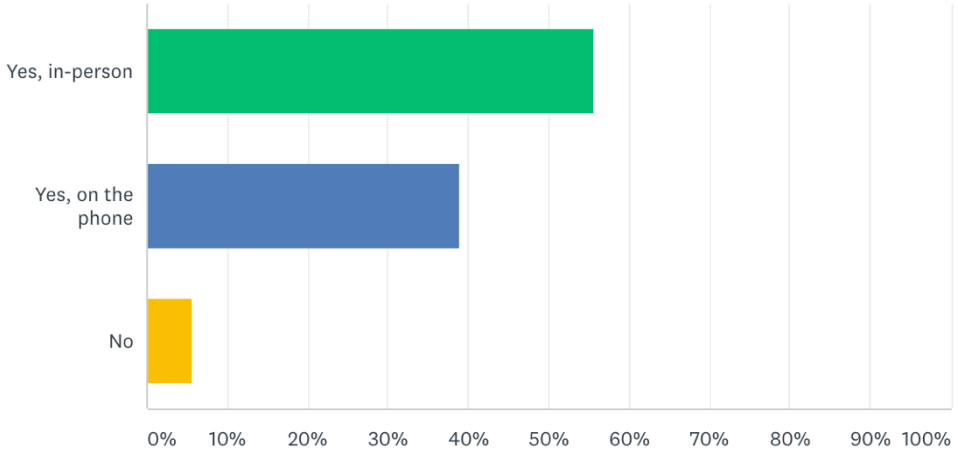
Project Timeline



Year One Report is Available

End Use Load Profiles for the U.S. Building Stock: Market Needs, Use Cases and Data Gaps is available now

Scheduling 2020 in-person TAG



- 36 respondents - 14 on the phone and 20 in person
- Most selected date was **Monday, April 13 PM – Tuesday April 14**
- **Same** format as last year, beginning with lunch on Monday

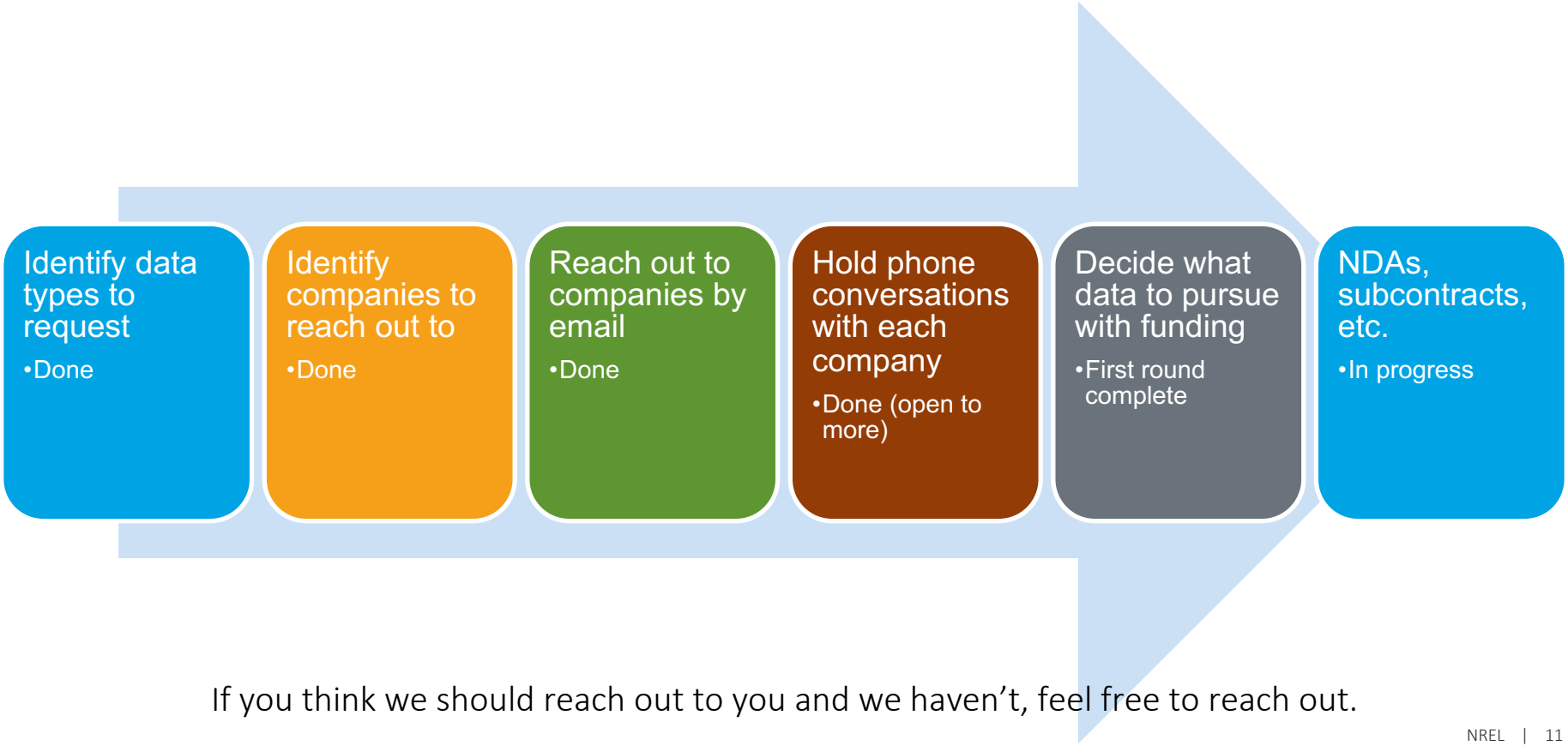
Key Milestones

2020	Complete models to represent stochastic behavior of discrete end-use events in building operation
	Complete framework for sensitivity analysis and uncertainty quantification
	Produce working but **uncalibrated** model of national residential and commercial building stocks that generates end-use load profiles
	Complete residential sector calibration for three regions Complete commercial sector calibration for two regions
2021	Complete **calibrated** model of national residential and commercial building stocks that generates average and typical end-use load profiles
	Publish dataset of end-use load profiles on one or more free, publicly accessible websites such as OpenEI.org, Data.gov, and the EPRI Load Shape Library
	Publish Technical Project Documentation that describes technical details, assumptions and methodologies used to develop and calibrate the models and create end-use load profiles
	Publish User's Guide describes approach, results, and applications (e.g., load forecasting, resource planning, program, and policy design)

Progress updates

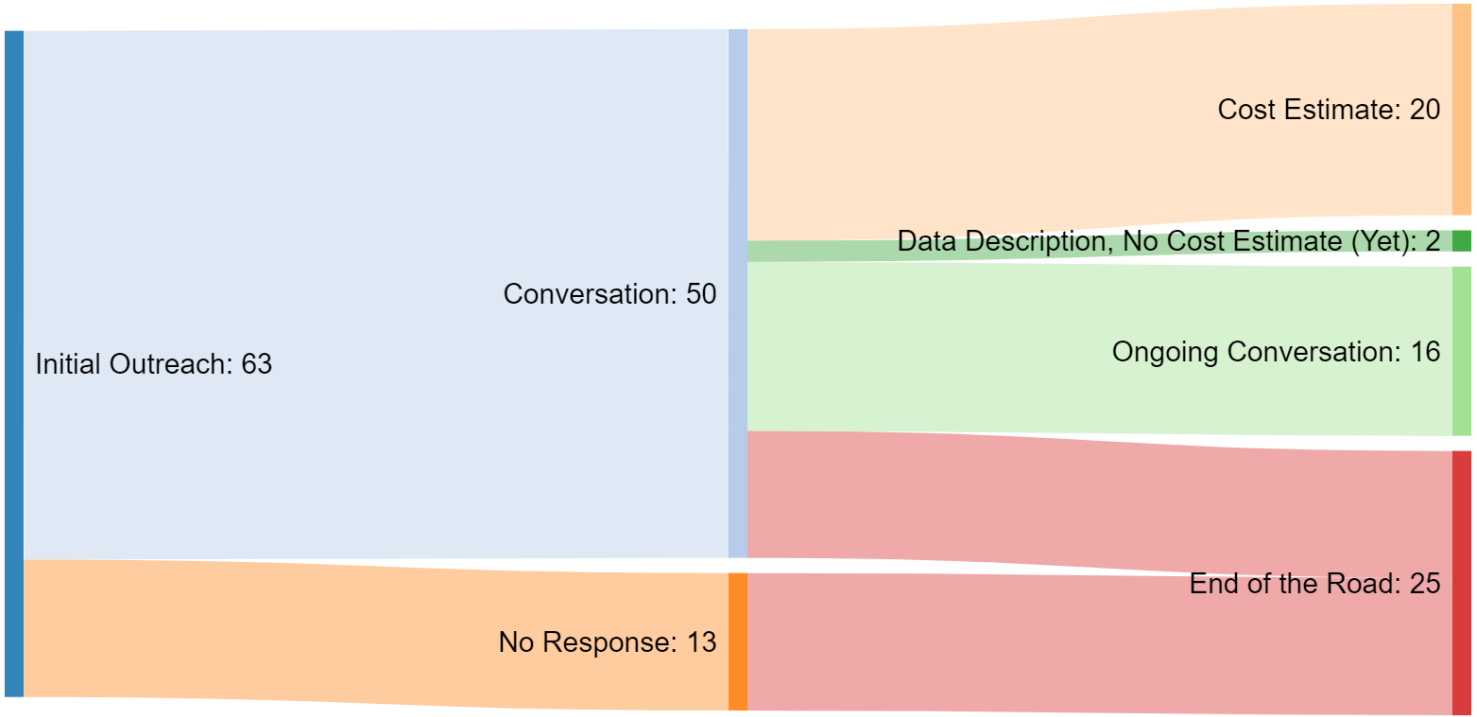
Calibration data procurement

Market Research for Funding Prioritization

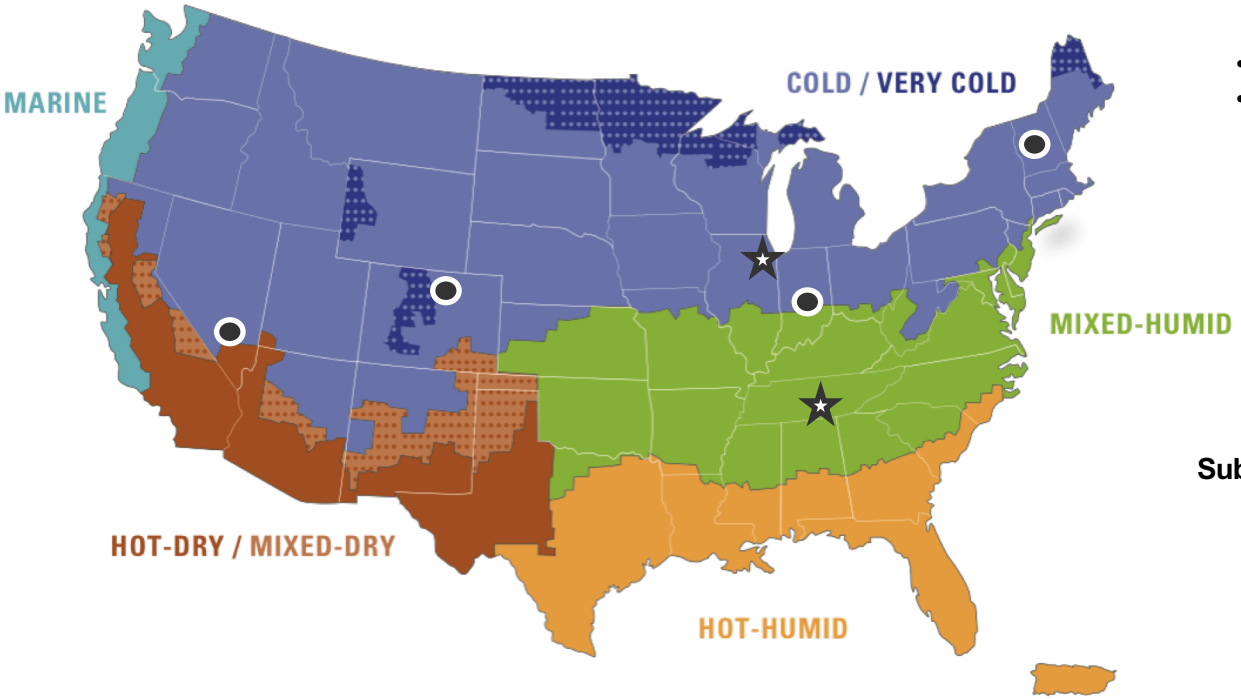


If you think we should reach out to you and we haven't, feel free to reach out.

Commercial Submeter Data: Outreach Status



AMI Data



AMI Target

- 6 datasets
- Representation in 5 climate zones

Substantial Utility AMI Datasets

Current status

★ Data in hand (2)

● NDA completed (4)

Additional 2 NDAs in process
Many more conversations underway

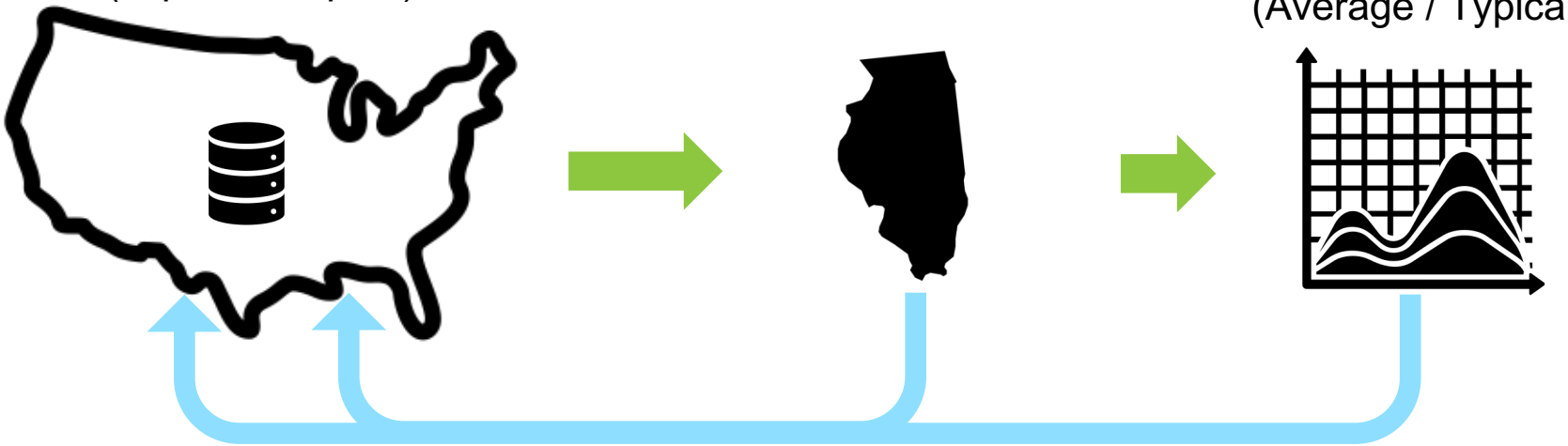
Residential calibration progress

Calibration Plan (1)

National ResStock / ComStock (improved inputs)

Regional calibration (AMI, ISO, LRD, Submetered)

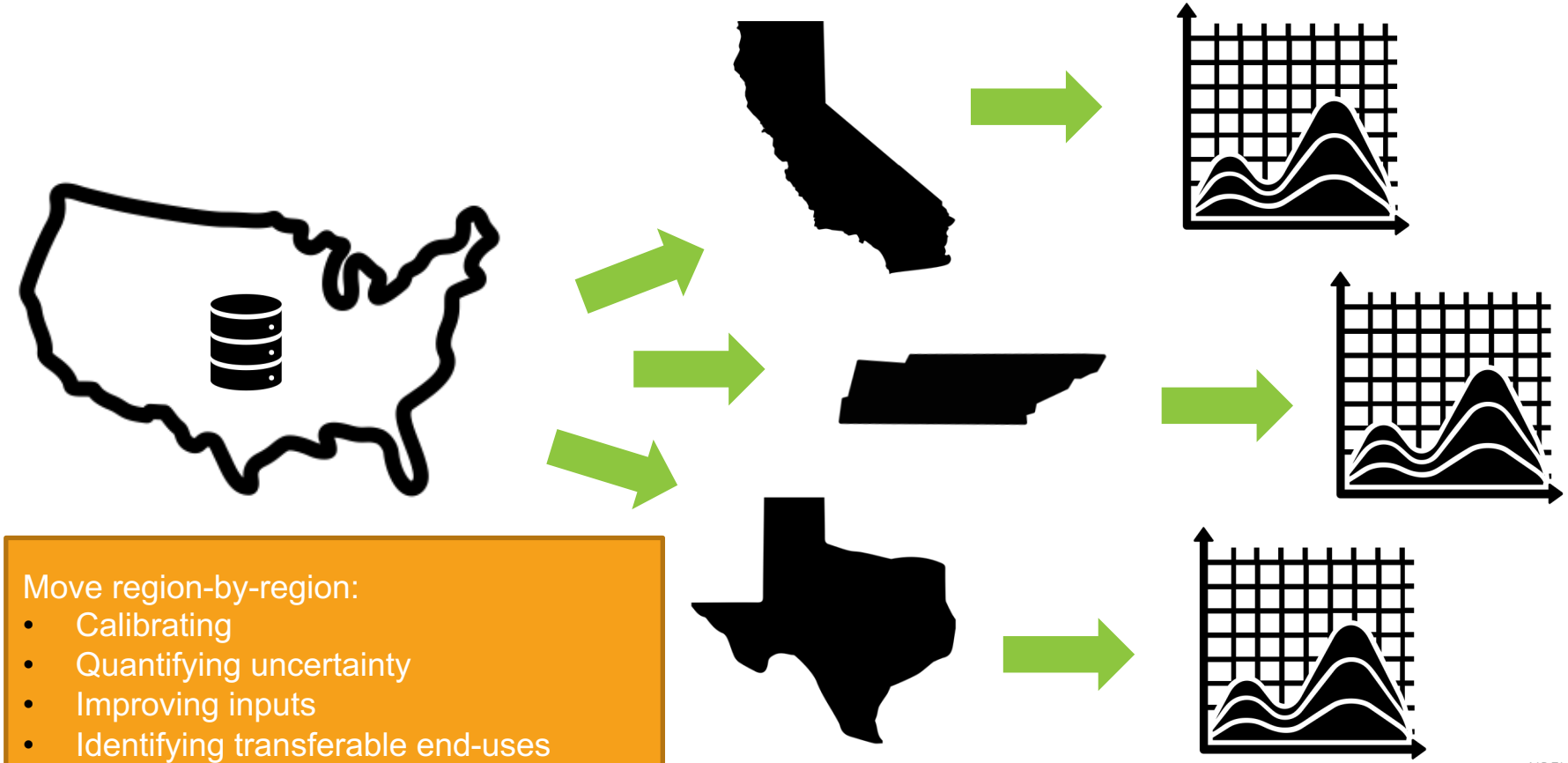
Regional Load Profiles & Occupancy Schedules (Average / Typical)



- Start with a region with high data coverage
- Update national model

Results from regional calibration improve national model and transfer to other regions (as appropriate)

Calibration Plan (2)



Move region-by-region:

- Calibrating
- Quantifying uncertainty
- Improving inputs
- Identifying transferable end-uses

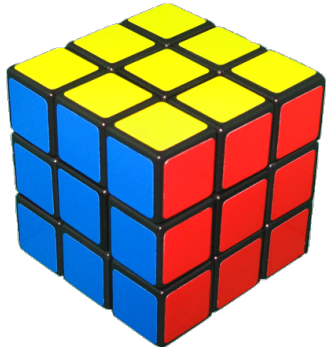
Calibration Plan (3)

Multifaceted Calibration

1. Annual – Whole-Building
2. Annual – End Uses
3. Annual – Diversity
4. Timeseries – Whole-Building
5. Timeseries – End Uses
6. Timeseries – Diversity

Each dimension has:

- metrics,
- visualizations,
- relevant data sources,
- relevant inputs to update

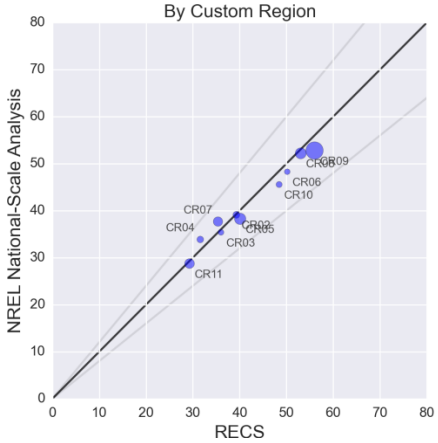


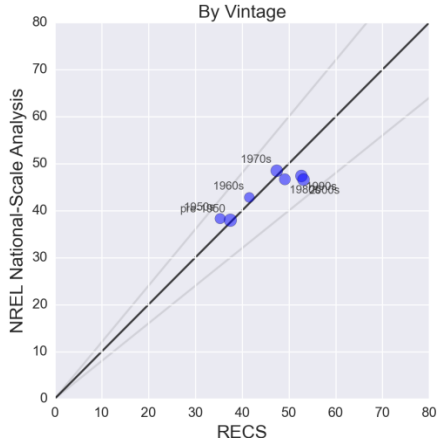
By calibrating six different dimensions, we can ensure accuracy by bounding errors and variability of results.

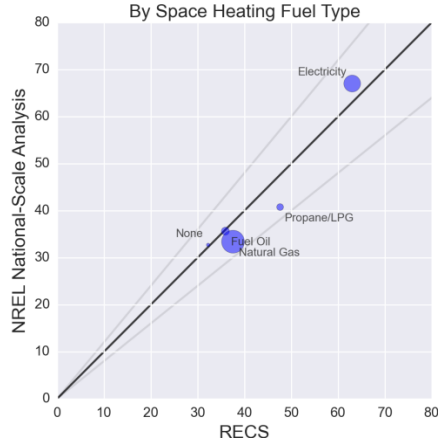
Previous calibration work – Single-Family Detached

Modeled (y-axis) vs. EIA 2009 RECS (x-axis) Average Source Energy per House: 10^6 Btu/yr

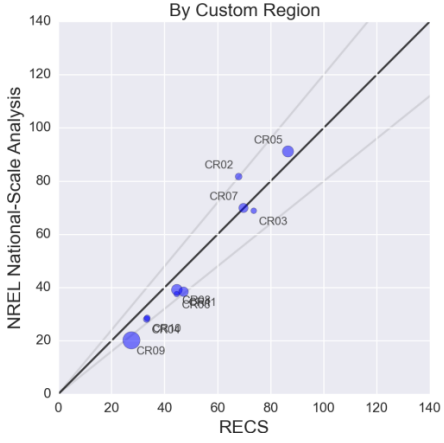
Electricity

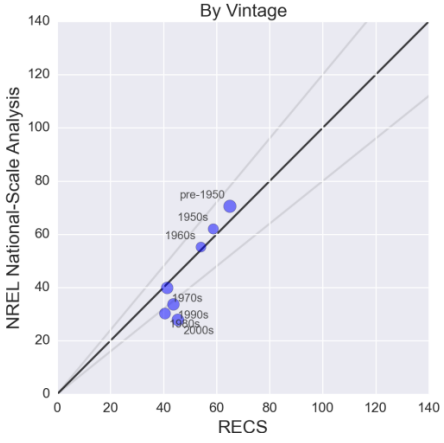


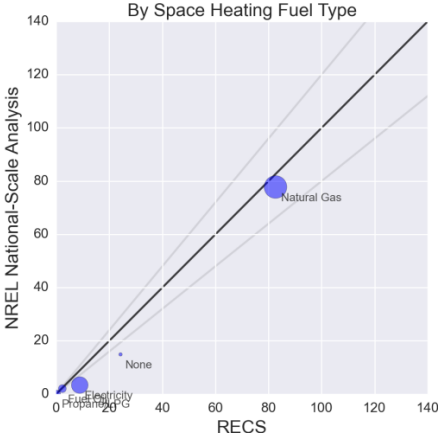




Natural Gas







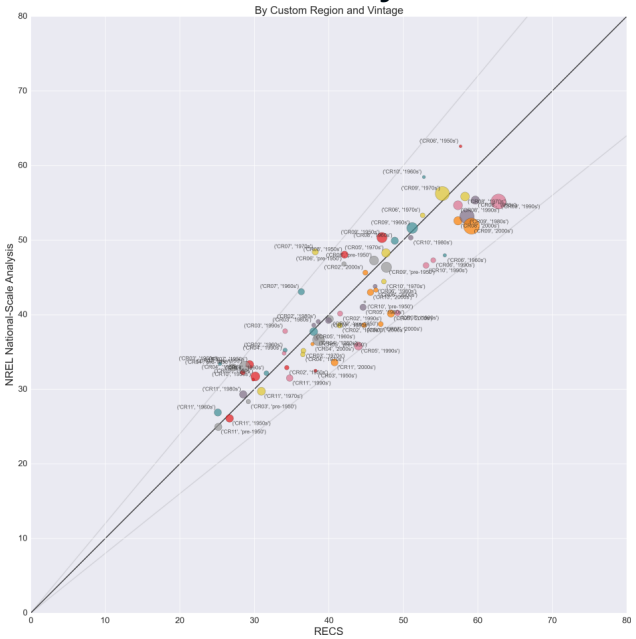
Previous calibration work – Single-Family Detached

Modeled (y-axis) vs. EIA 2009 RECS (x-axis)

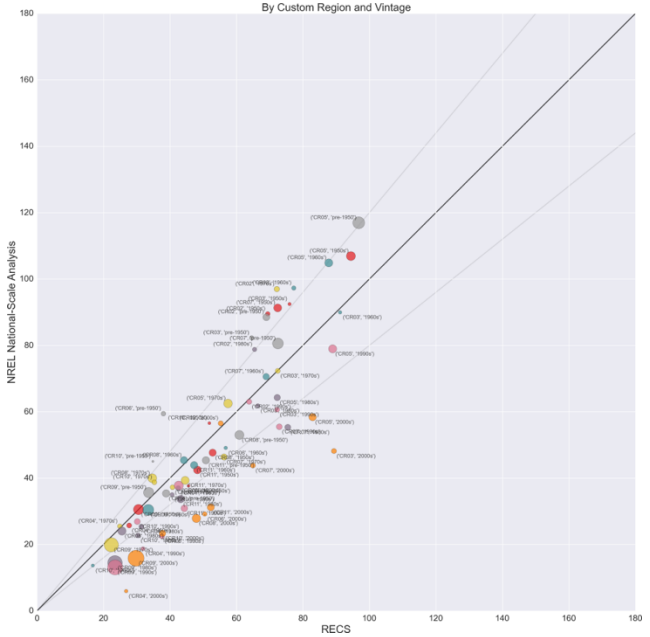
Average Source Energy per House: 10^6 Btu/yr

Aggregated by Region/Vintage Combinations

Electricity



Natural Gas



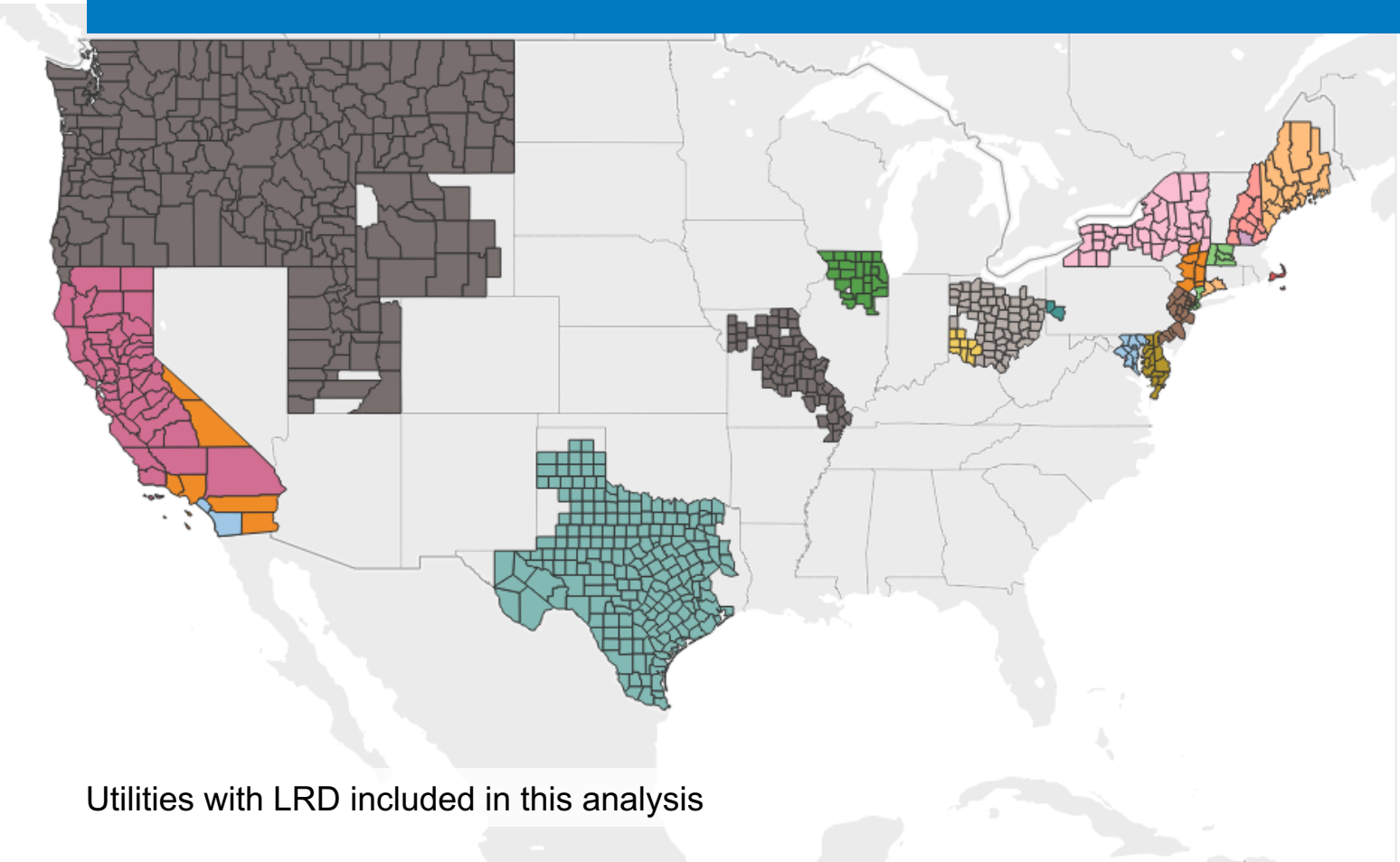
Res. calibration - Initial comparison

- We compared:
  - ResStock annual results by utility to EIA sales data
  - ResStock time series results to load research data (LRD) from 21 utilities and ERCOT.
- Discrepancies were similar to those found in previous projects:
  - ResStock generally overpredicts peak load and underpredicts on baseload.
  - ResStock predicts an early peak load compared to timeseries load data.
- We have identified possible reasons for discrepancies.
- The results of this analysis are largely as anticipated and will be addressed during calibration.

Res. calibration - Initial comparison

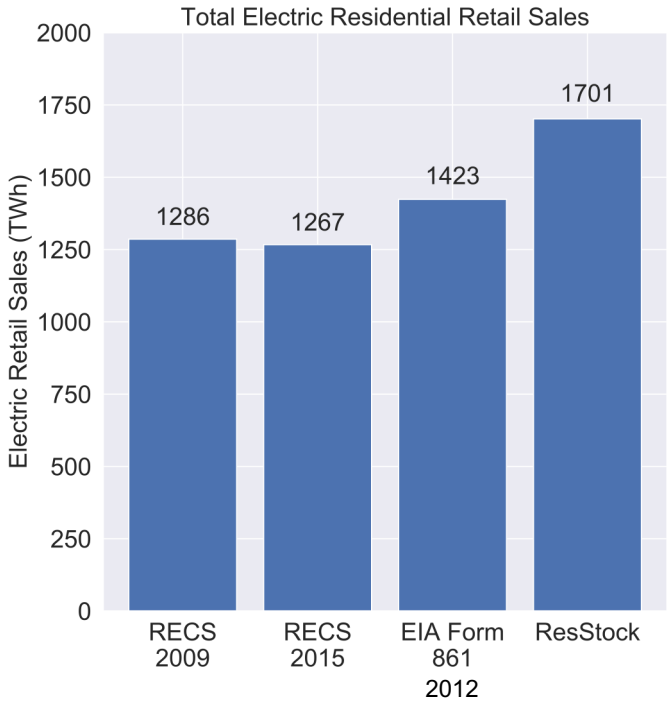
- Residential annual electric retail sales: These data are obtained from EIA form 861, which provides annual electric retail sales from all the utilities nationwide. https://www.eia.gov/electricity/data/eia861/
- Annual volume of natural gas delivered: These data are obtained from EIA's natural gas data. The volume of delivered natural gas is provided by sector and by state. https://www.eia.gov/naturalgas/data.php
- Load research data: The main source of data for this comparison is hourly LRD representing the residential sector in aggregate for different utilities.
  - Some utilities have provided residential sector wide total load (i.e., MW), while others have provided the total residential sector load normalized by the number of customers (i.e., average kWh per customer).
  - In the case where only the normalized customer data are available, these profiles are scaled by the annual electric retail sales from EIA form 861 to get sector totals.
- ERCOT load data: Unlike the rest of the LRD which are from 2012, load data from the ERCOT territory was obtained for 2016.

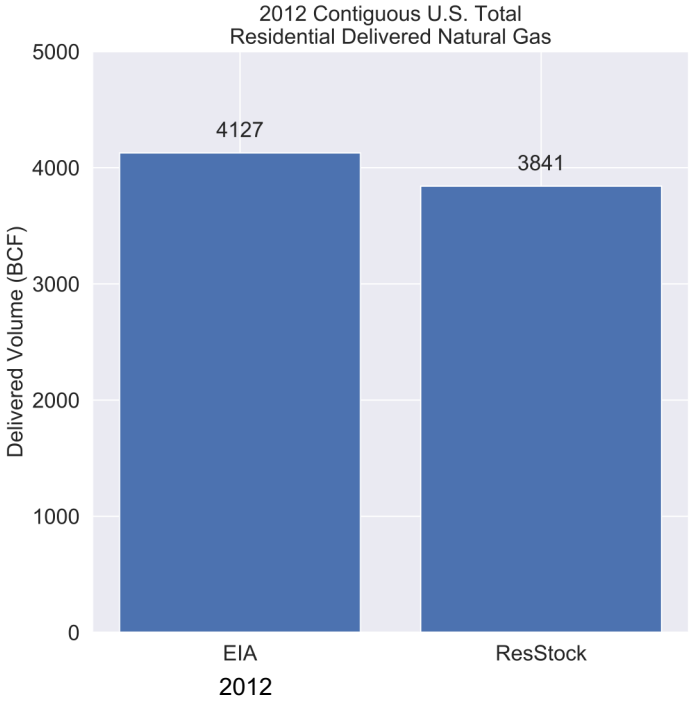
Res. calibration - Initial comparison



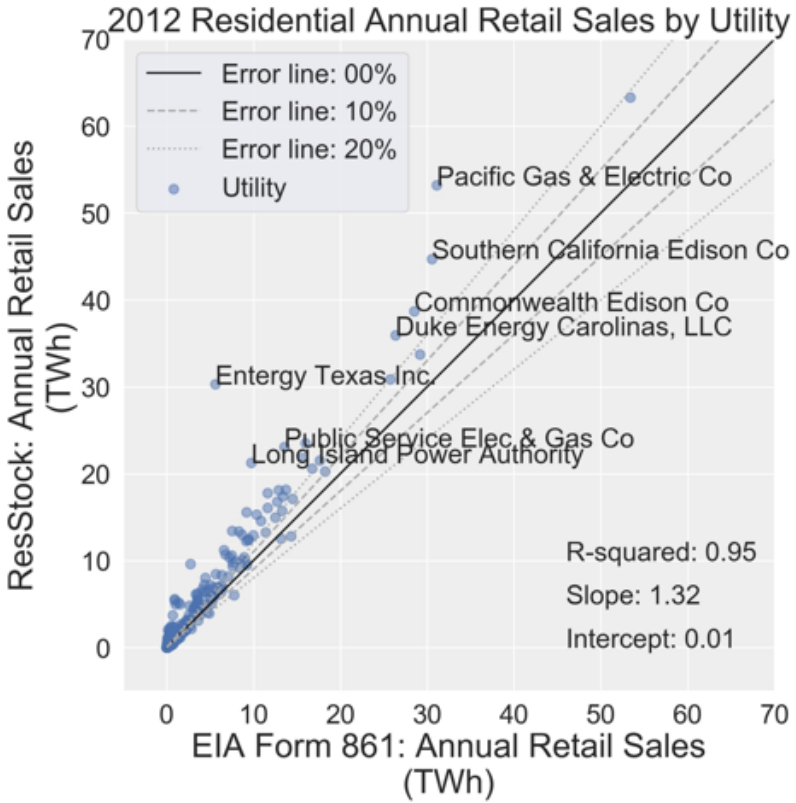
Utilities with LRD included in this analysis

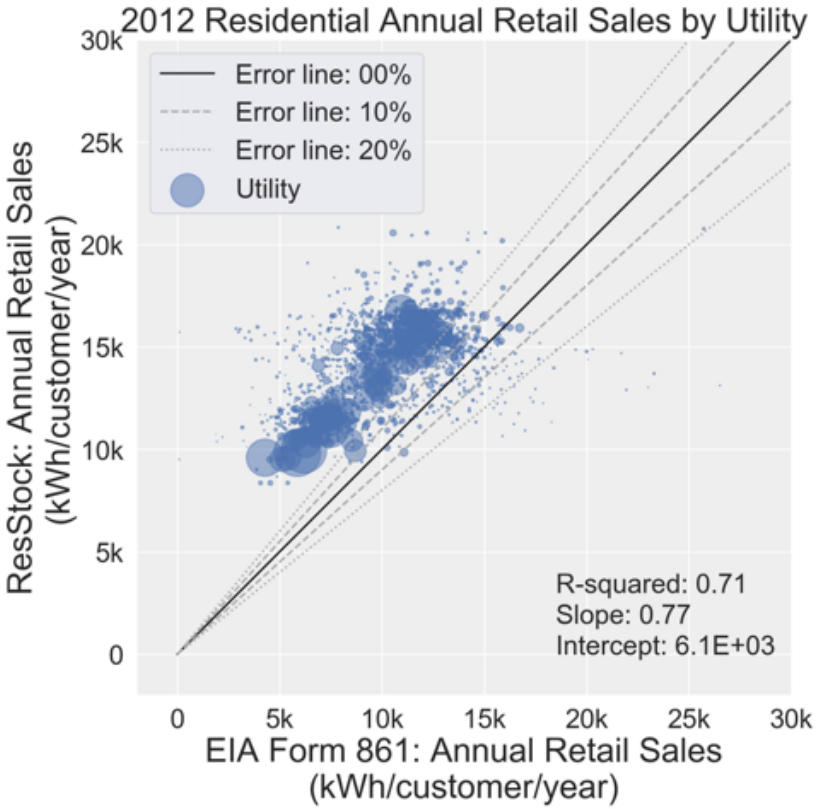
Res. calibration - Initial comparison





Res. calibration - Initial comparison





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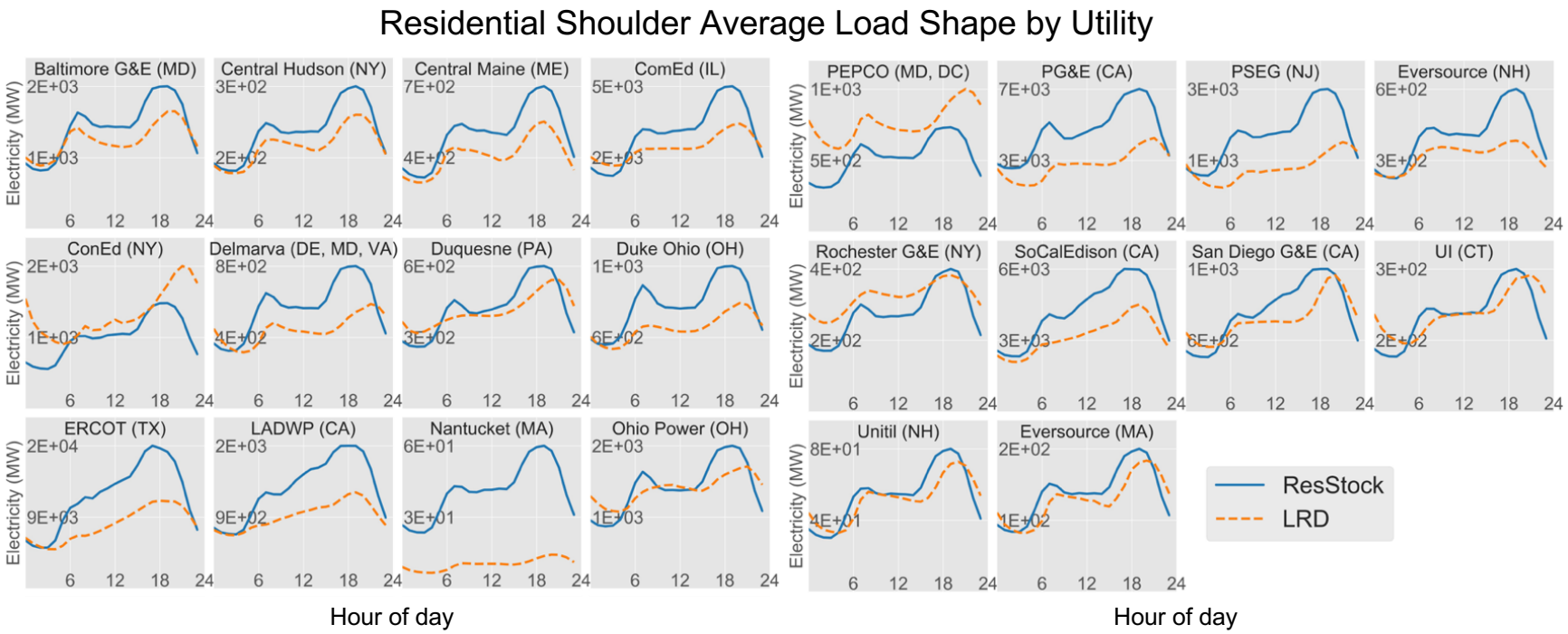

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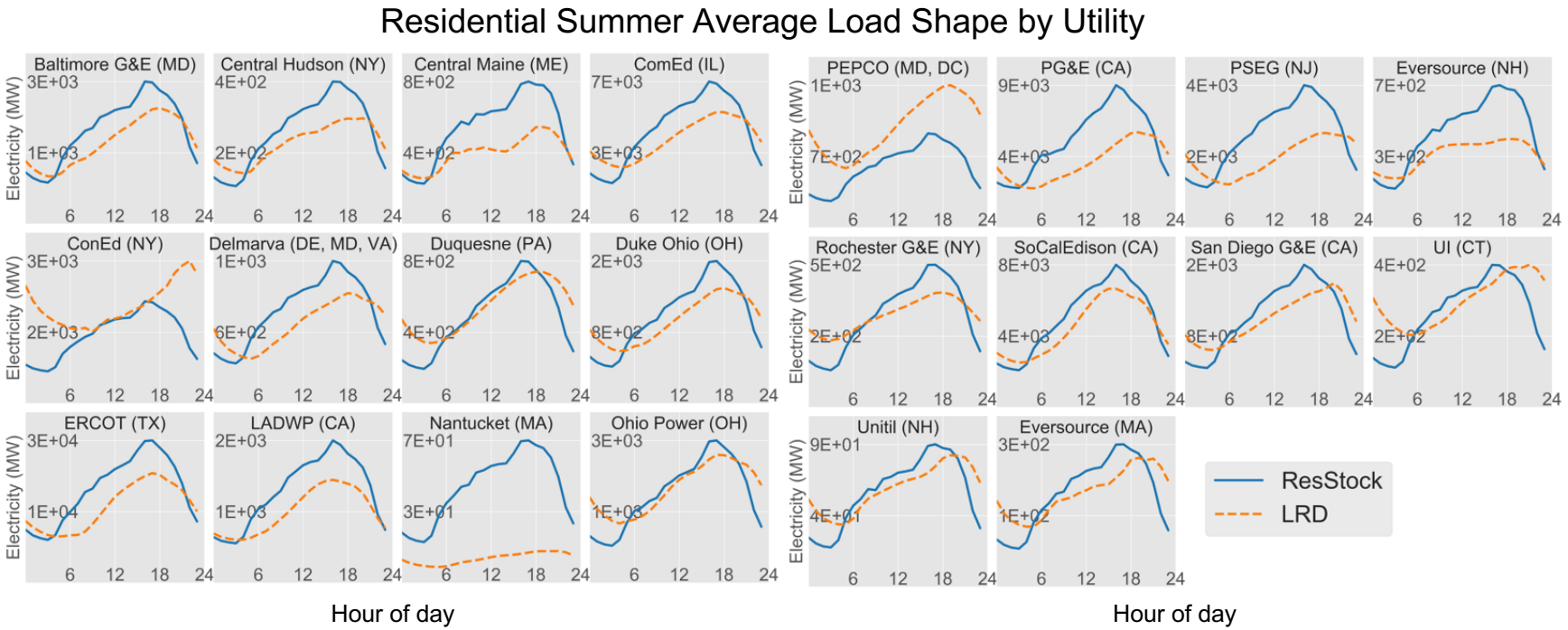

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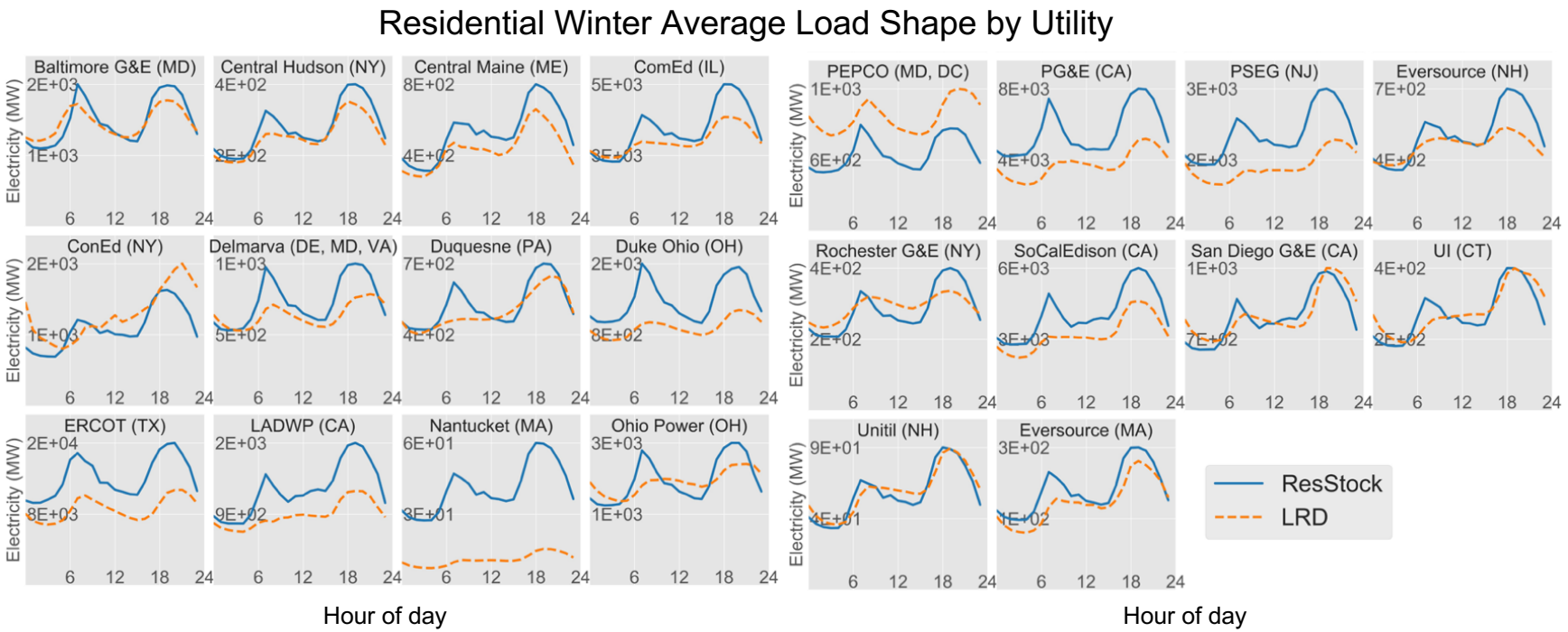

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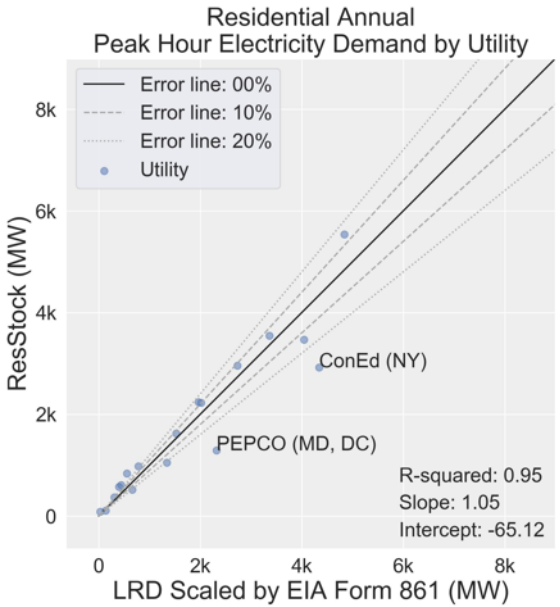

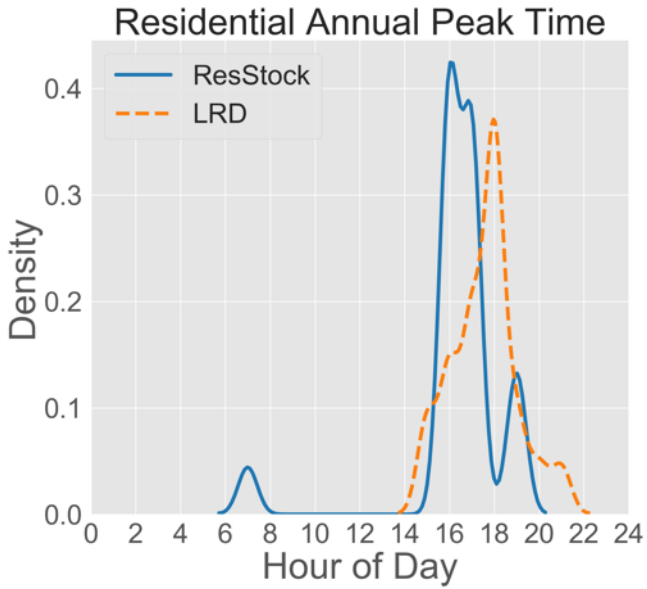

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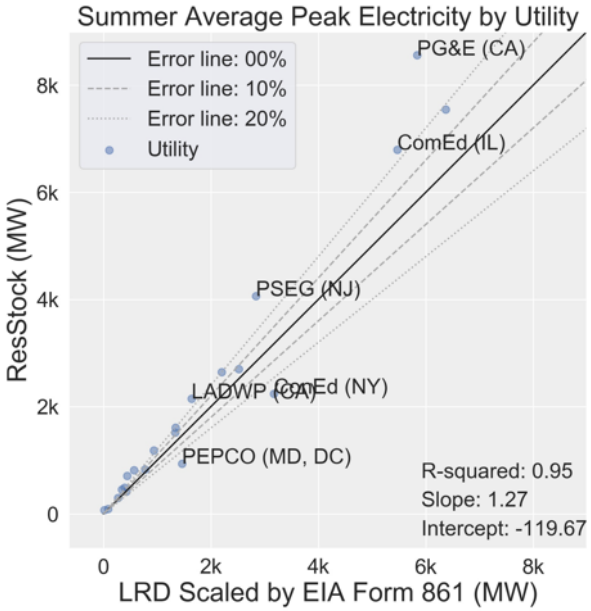
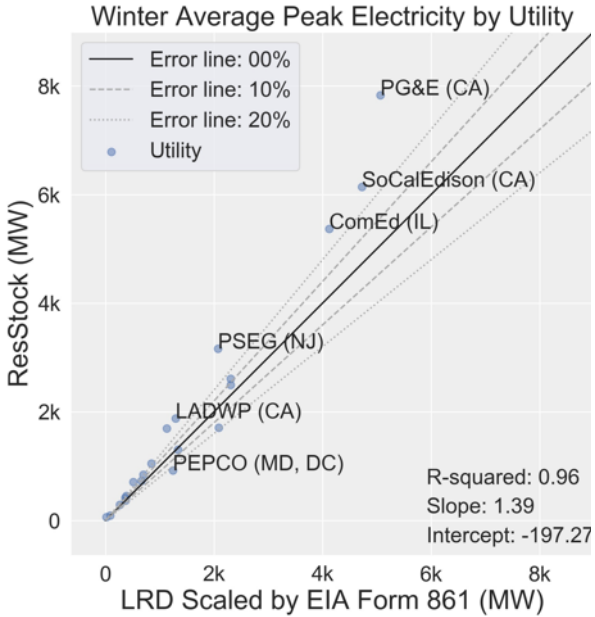
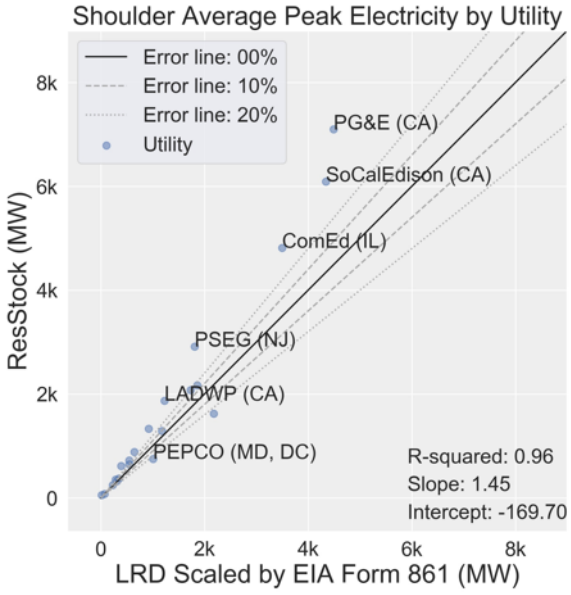
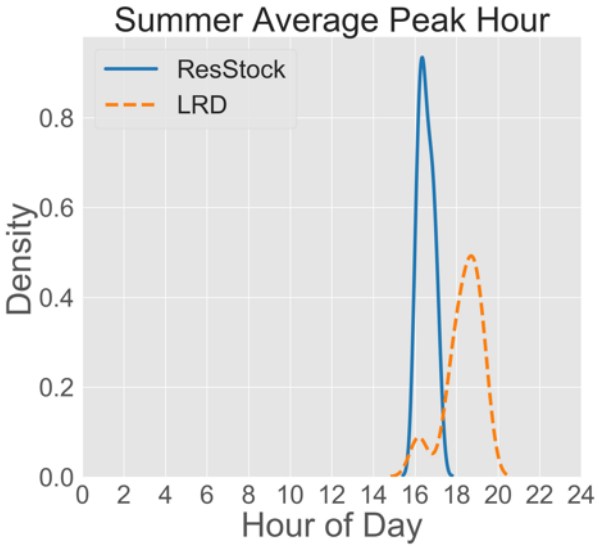
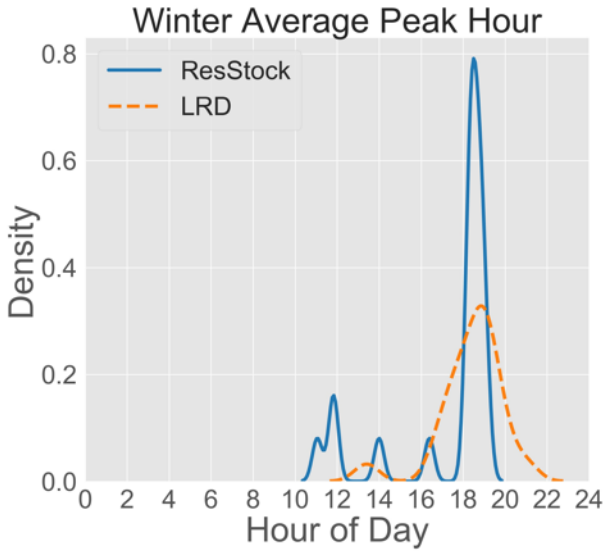


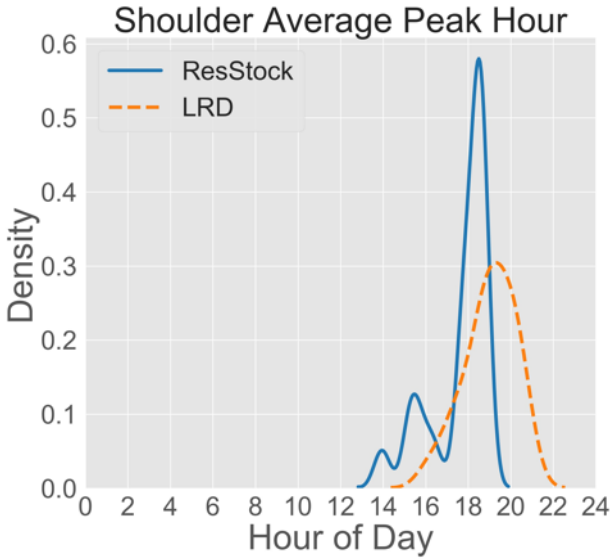




Res. calibration - Initial comparison







Res. calibration - Initial comparison

Possible reasons for discrepancies include:

- Varying definitions of the residential building stock and the number of customers
- Representation of multifamily units and their energy consumption
- Geospatial resolution

Discussion

We are going to unmute all of the phone lines, so please mute yourself if you are not speaking.

Residential end use transferability

Question: Are residential end use patterns the same across regions?

Residential end use transferability

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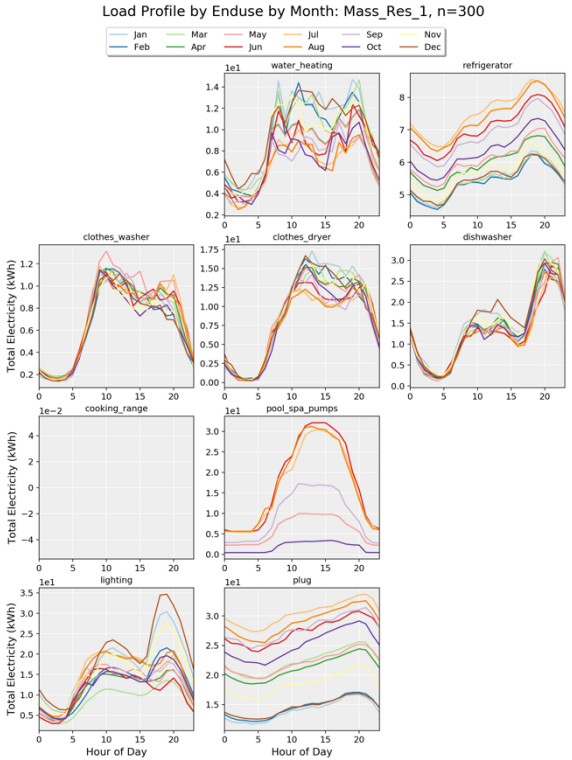
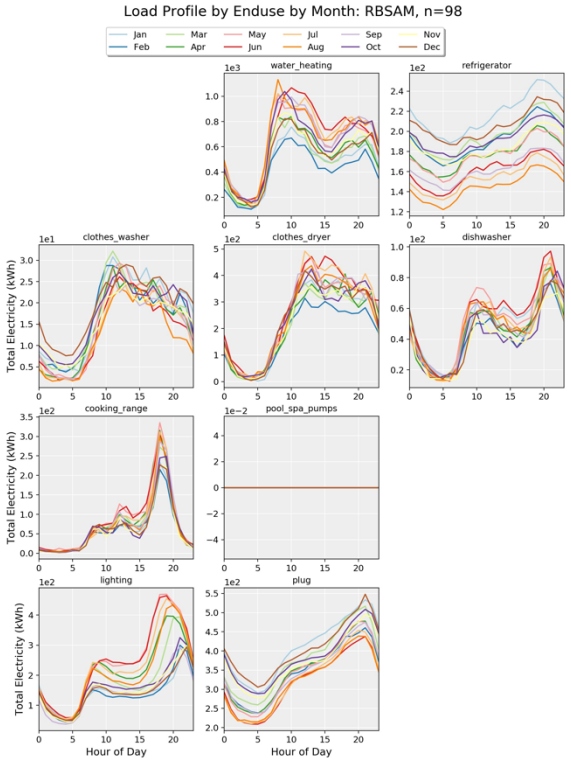
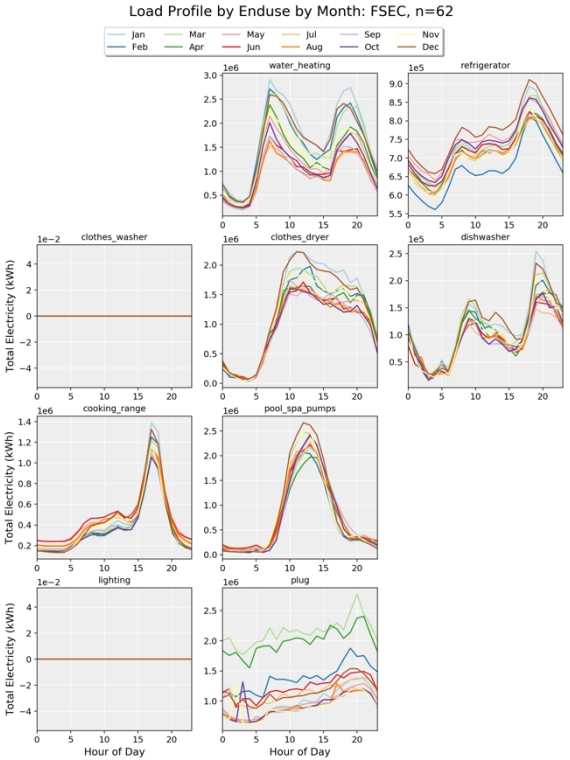
- Navigant Massachusetts Residential Baseline Study **(Mass Res 1)**
  - **356 sites,** metered between May 2017 and April 2018
  - **Massachusetts**, representative sample
- NEEA Residential Building Stock Assessment: Metering Study **(RBSAM)**
  - **101 homes,** metered from 2012-04-01 to 2014-07-31
  - **Pacific Northwest**, representative sample
- Florida Solar Energy Center - Phased Deep Retrofit Study **(FSEC)**
  - **56 homes,** metered from 2012 to 2016
  - Central Florida, biased sample
- Pecan Street Dataport **(Pecan Street)** – Not shown (still awaiting approval to present)
  - **998 homes,** metered between 2011 to 2014
  - **Texas** (97%), biased sample

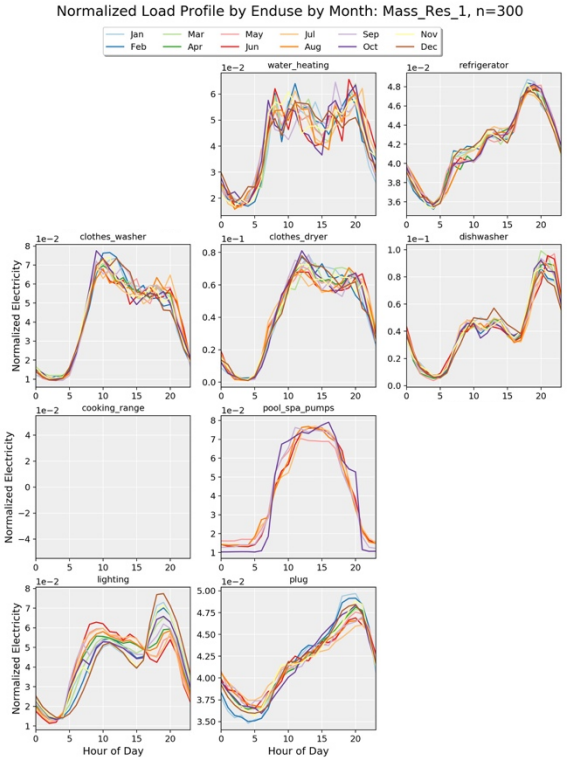
Residential end use transferability

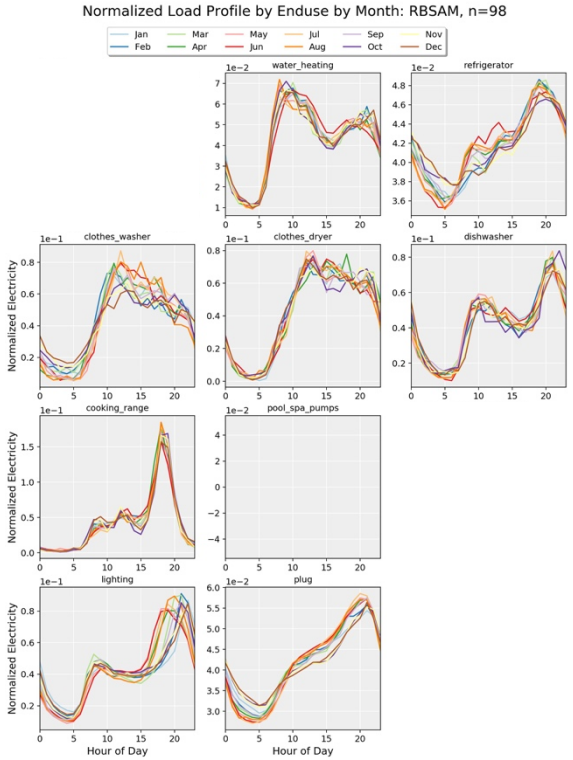


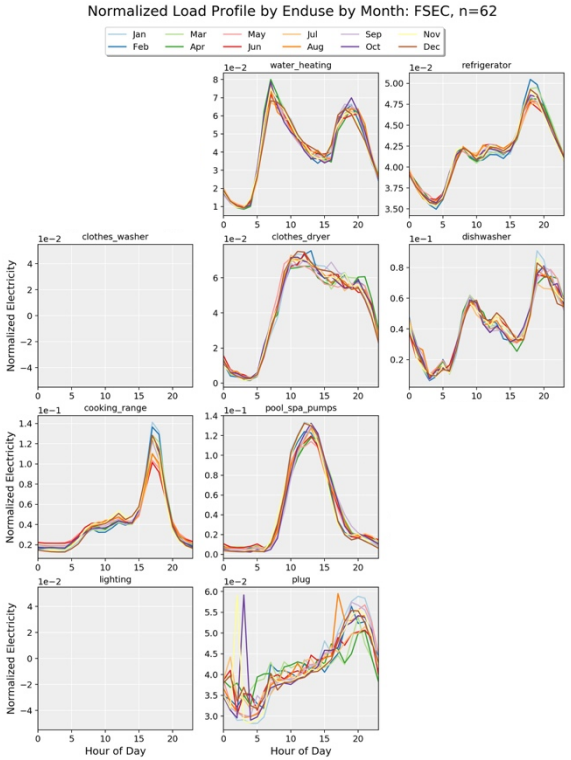




Residential end use transferability



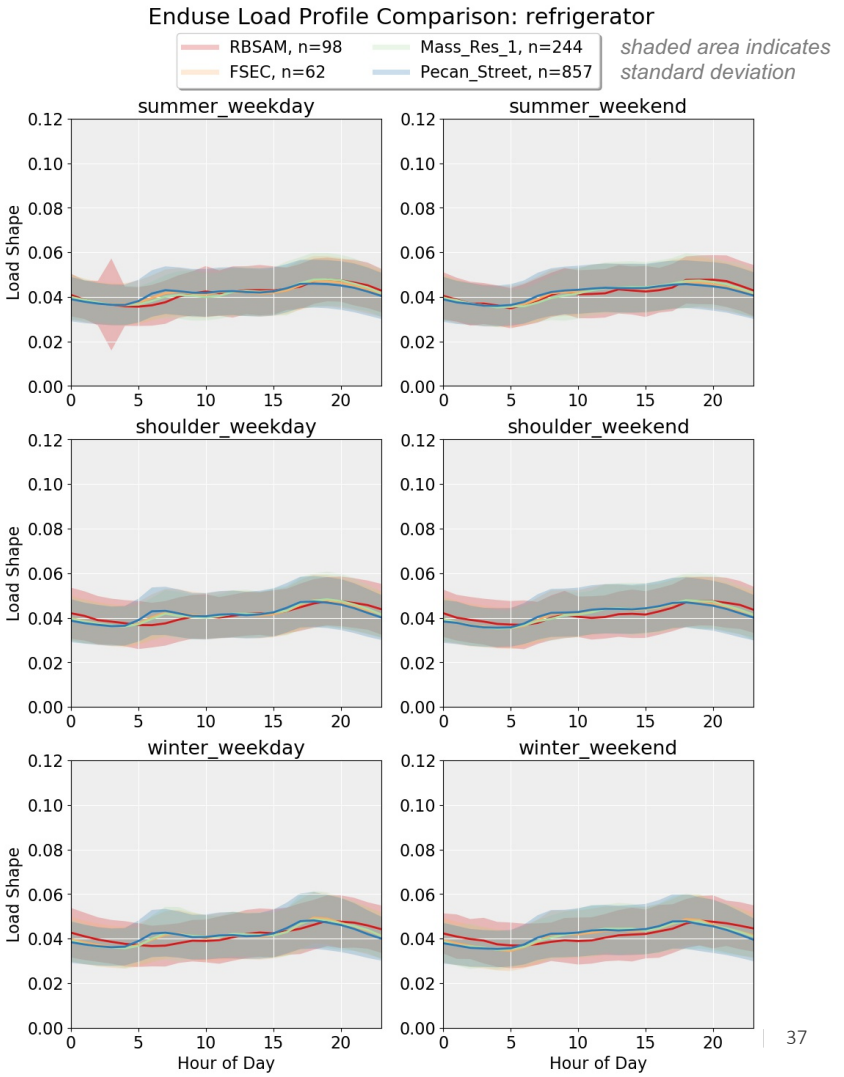




Residential end use transferability

Refrigerator (primary)
Transferable across regions?

Yes.

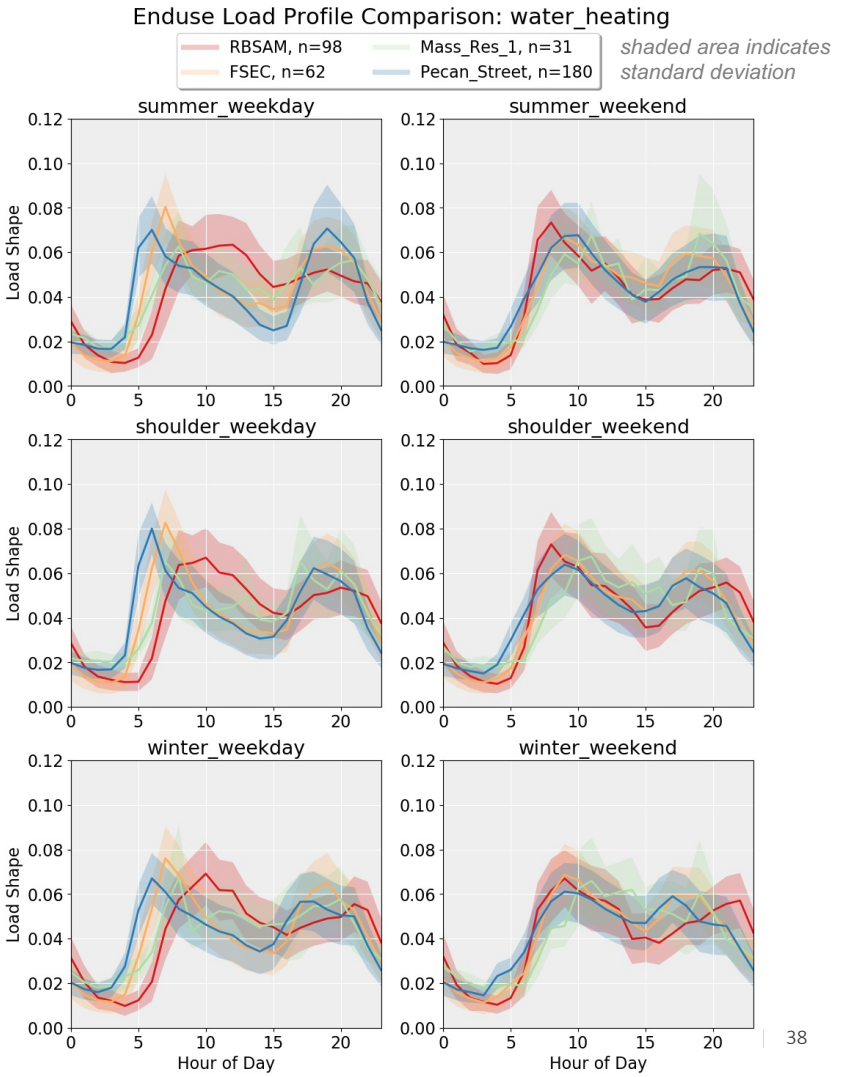


Residential end use transferability

Water heating (electric)
Transferable across regions?

Yes, except RBSAM

- *Morning use later on weekdays*

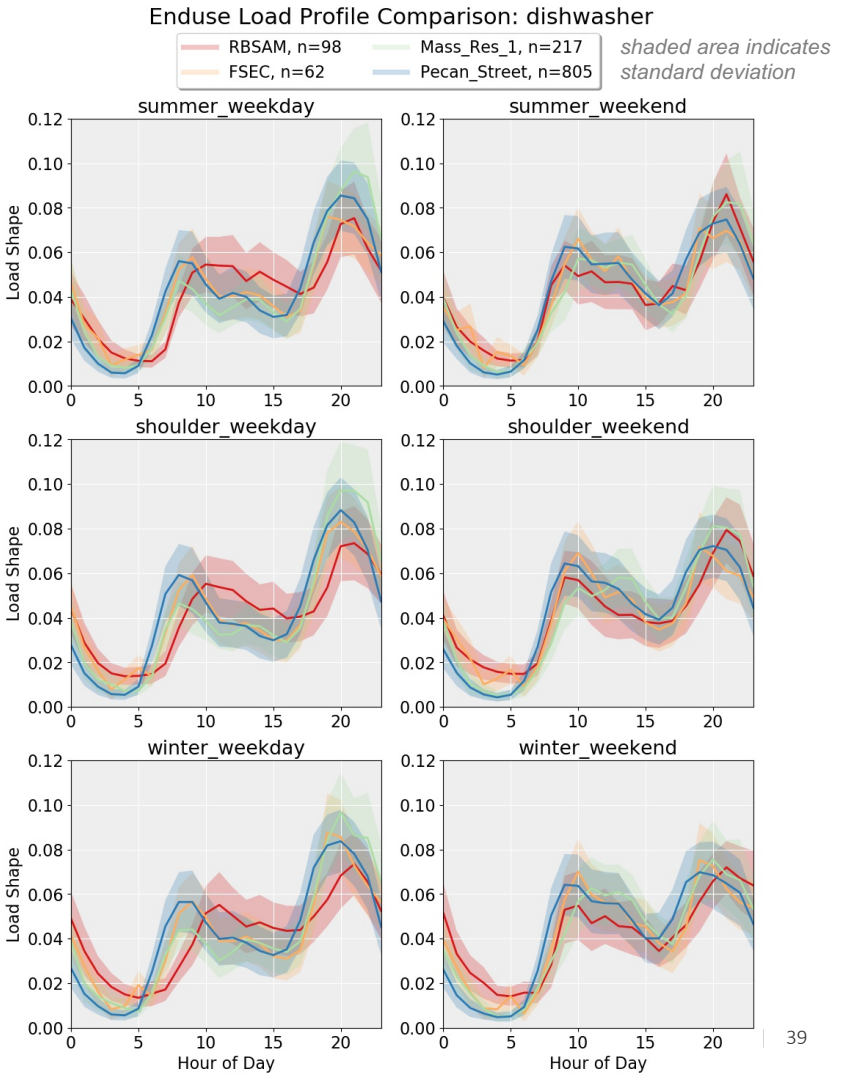


Residential end use transferability

Dishwasher
Transferable across regions?

Yes, except RBSAM

- *Morning use later on weekdays*

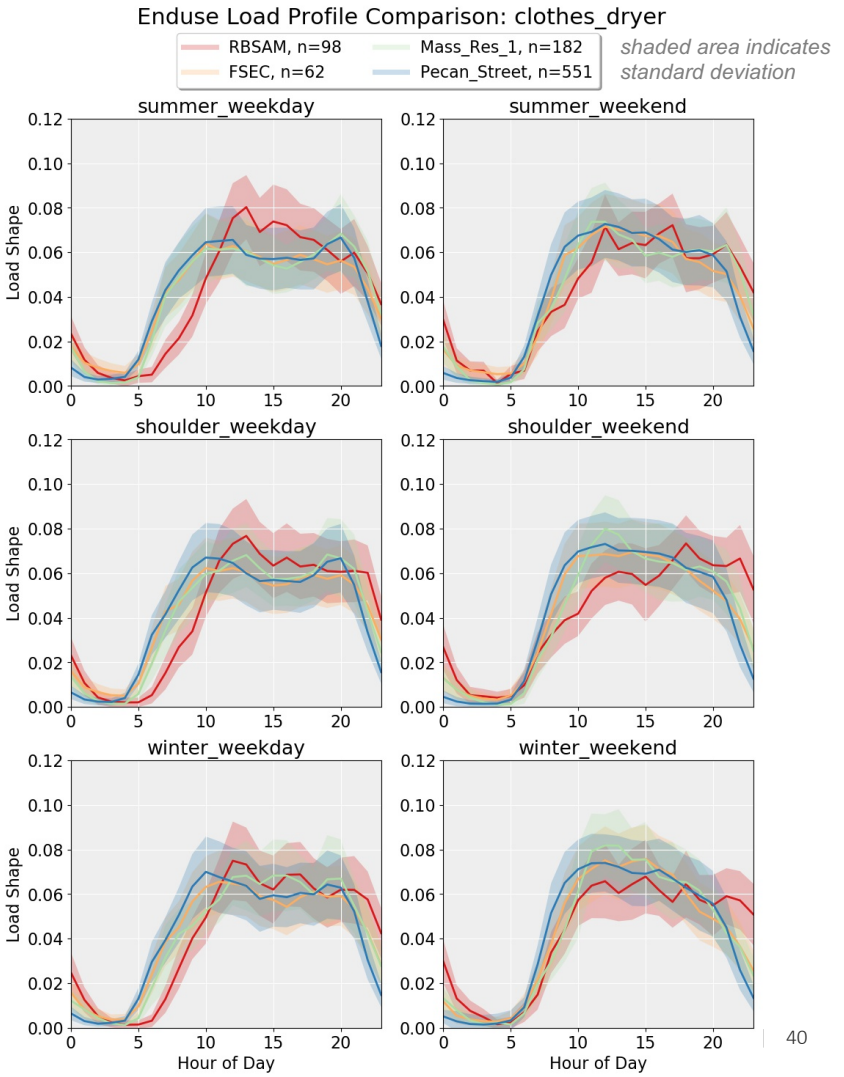


Residential end use transferability

Clothes Dryer
Transferable across regions?

Yes, except RBSAM

- *Morning use later on weekdays*

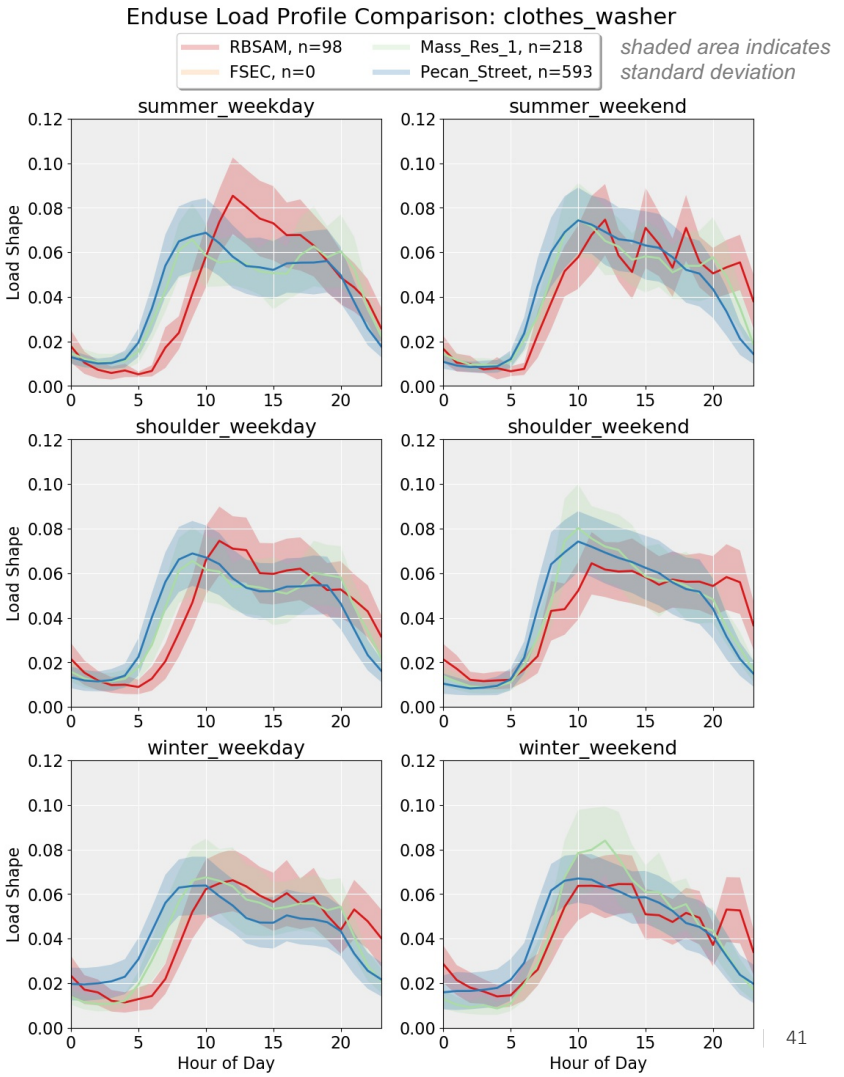


Residential end use transferability

Clothes Washer
Transferable across regions?

Yes, except RBSAM

- *Morning use later on weekdays*

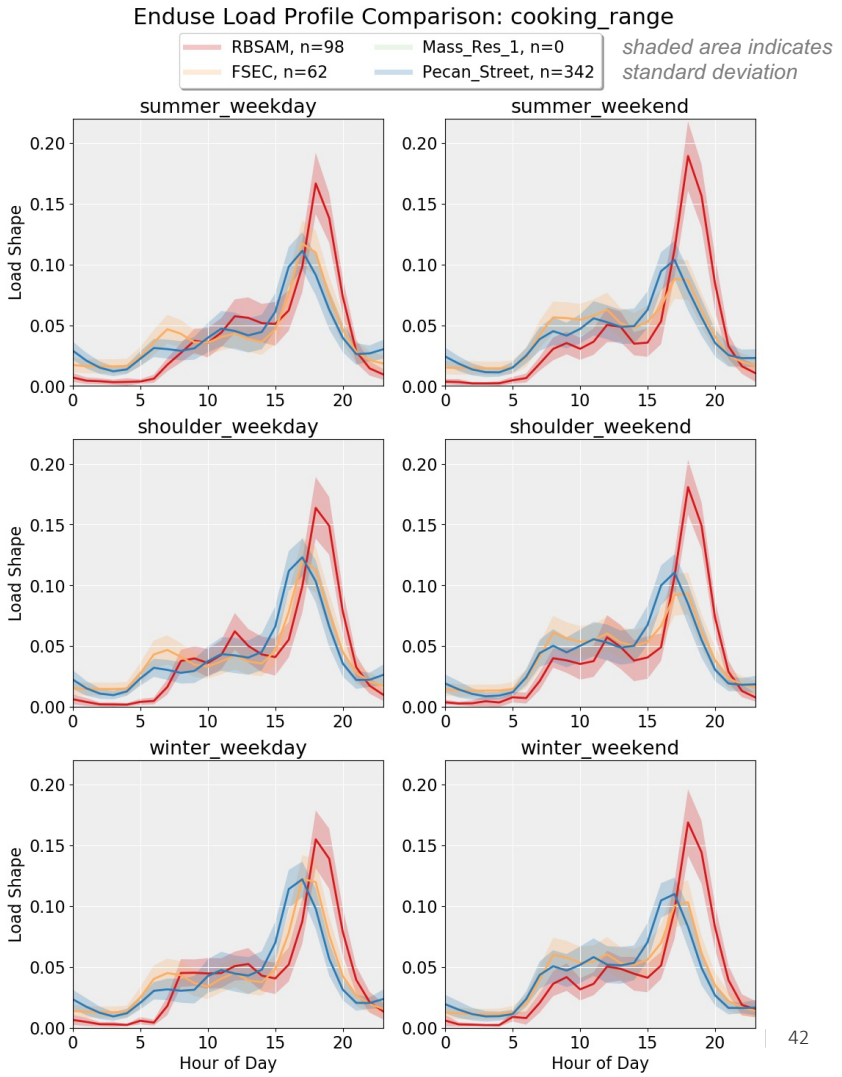


Residential end use transferability

Cooking Range (Stove/Oven)
Transferable across regions?

Yes, except RBSAM

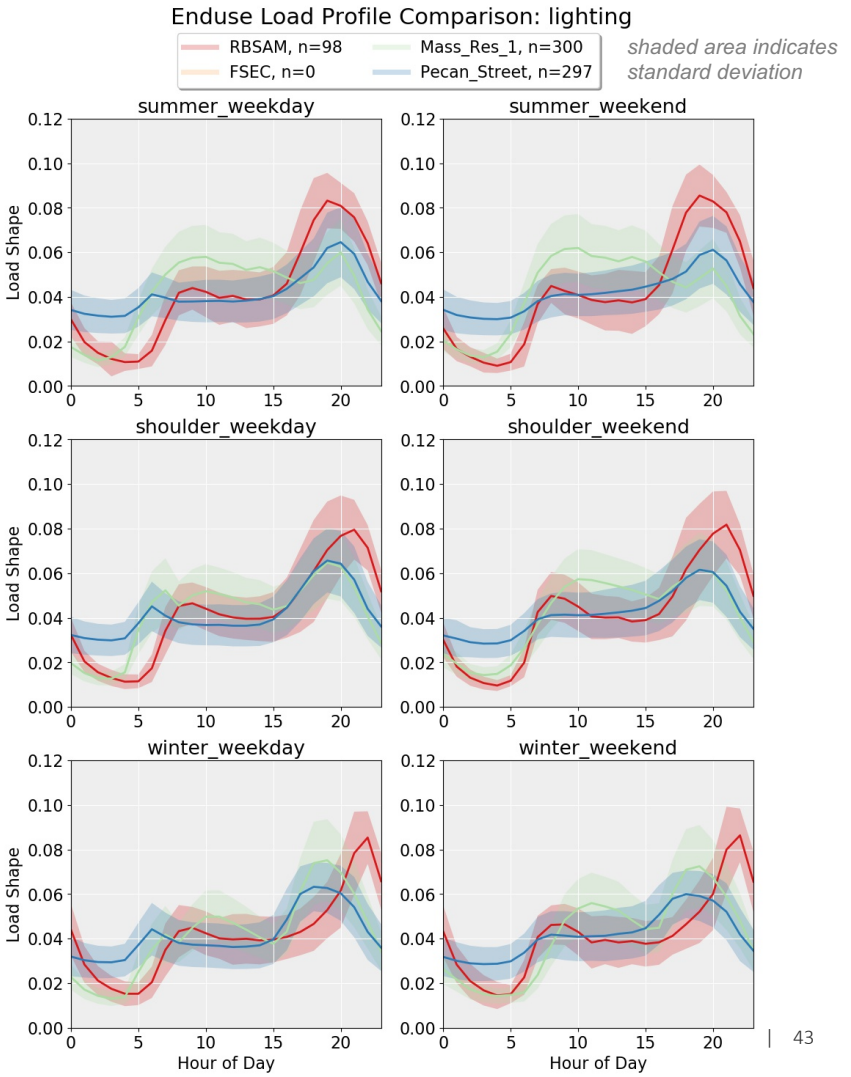
- *Morning use later on weekdays*
- *Larger evening peak*



Residential end use transferability

Lighting
Transferable across regions?

No. How much can be explained by sunrise and sunset time differences?



Discussion

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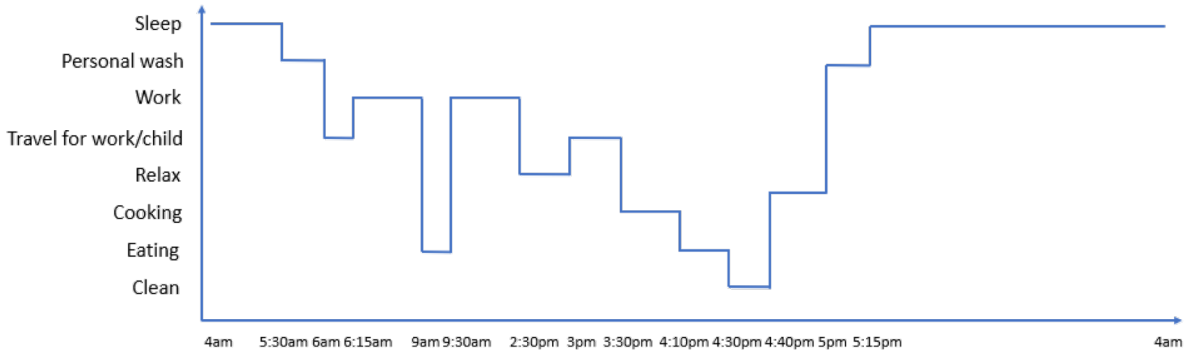
Occupancy modeling

Commercial occupancy modeling (1)

- LBNL team is leveraging previous work on modeling office building occupant behavior
- Major tasks
  - Integration into ComStock (largely complete)
  - Extension to other high priority building types: food service, lodging

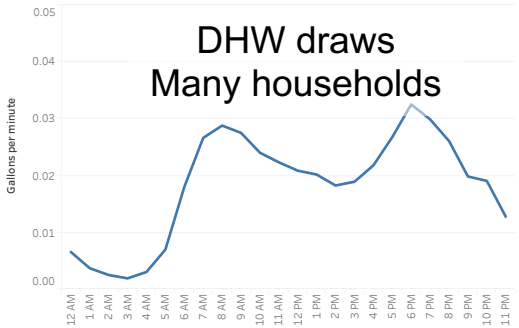
Residential occupancy modeling - Data sources (1)

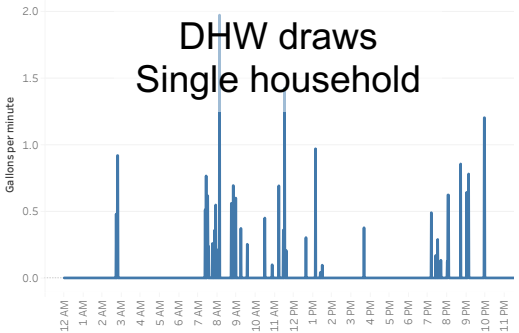
- American Time Use Survey (ATUS)
  - One respondent in a house reports their activities and corresponding timeline on the previous day
  - ~190k respondents in total from 2003 – 2017 (we use 2013–2017 only)
  - Metadata: age, employment status, children, other household members, etc.
  - Activities of interest: sleep, away, cooking, laundry, dishwashing, personal hygiene



Residential occupancy modeling - Data sources (2)

- NREL DHW Event Schedule Generator
  - Based on two studies (1200 households) from American Water Works Association (AWWA)
  - Household DHW events: sink, showers, baths, dishwasher, clotheswasher
  - Start time, duration, flow rates
- Others:
  - RBSAM
  - Pecan St.
  - FSEC
  - NREL lab appliance data

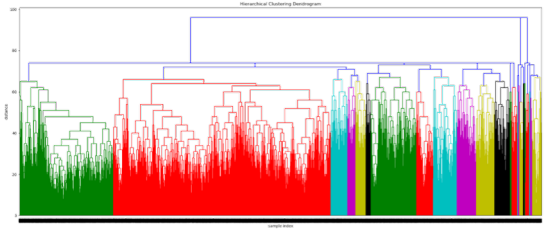




Residential occupancy modeling – Approach (1)

Pre-simulation steps that happen once

1. Run clustering algorithm to sort ATUS data into major occupant patterns (e.g., daytime occupancy)
2. For each cluster, generate set of matrices describing probability of transitioning from one activity to another in 15-minute intervals over the day (sleep, away, cooking, laundry, dishwashing, personal hygiene)



Transition Probability Matrix

$$P_t = \begin{bmatrix} P_{0,0} & P_{0,1} & P_{0,2} \\ P_{1,0} & P_{1,1} & P_{1,2} \\ P_{2,0} & P_{2,1} & P_{2,2} \end{bmatrix}$$

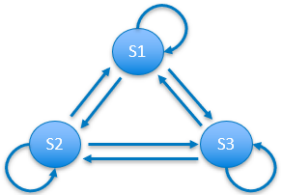
Residential occupancy modeling – Approach (2)

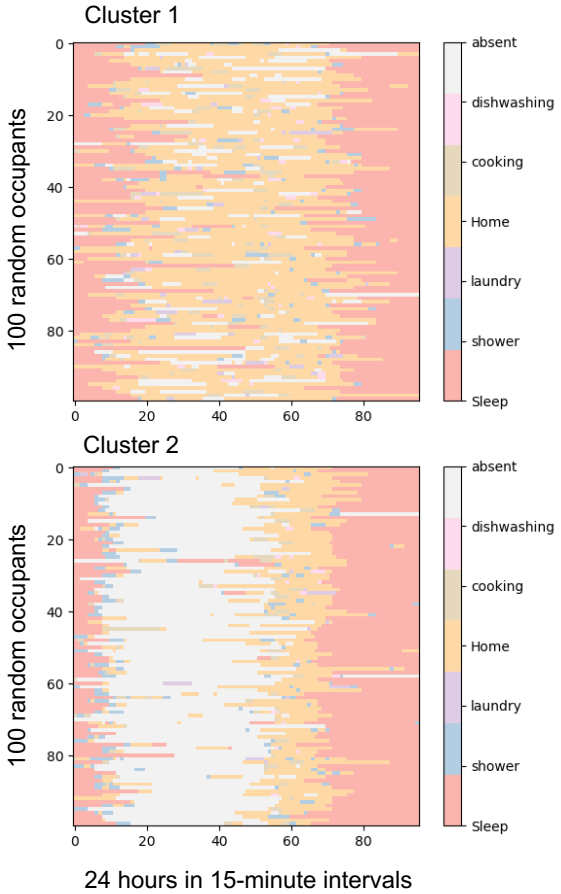
Steps happen on-the-fly in OpenStudio runs

1. For a given household, randomly select occupant patterns for each member from available clusters
2. Using transition probability matrices, run *time-inhomogeneous Markov Chain* simulations for each occupant in the household

Transition Probability Matrix

$$P_t = \begin{bmatrix} P_{0,0} & P_{0,1} & P_{0,2} \\ P_{1,0} & P_{1,1} & P_{1,2} \\ P_{2,0} & P_{2,1} & P_{2,2} \end{bmatrix}$$





Residential occupancy modeling – Approach (3)

Steps happen on-the-fly in OpenStudio runs

3. Randomly sample duration and flow rates for **occupant-level DHW events**: shower/bath, clothes washer, and dishwasher events (using AWWA data)
4. Merge activity patterns for occupants into household schedules
   - Combine overlapping cooking, dishwashing into single events
   - Shift overlapping laundry cycles to be consecutive
5. Randomly sample start time, duration and flow rate **for household-level DHW events**: sink events (using AWWA data)
6. Modify lighting and plug load schedules to account for household-level occupancy status
7. Export all schedules to .csv file read by OpenStudio objects

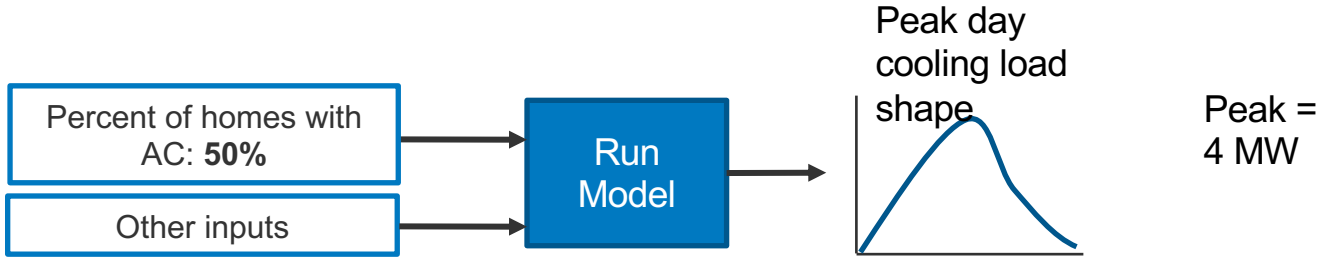
Residential occupancy modeling – Status (1)

- On track for working version integrated with ResStock by March 31
- Will need to compare ATUS-based patterns against Mass, RBSAM, FSEC, Pecan St., etc. patterns seen in transferability study
- Plan to incorporate demographic variables (age, employment status, number of household members, etc.) and associate with location based on U.S. Census/American Community Survey data

Uncertainty quantification framework

Example of UQ

Without UQ



Peak = 4 MW

Example of UQ

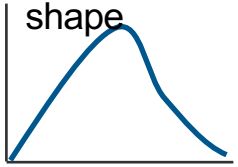
Without UQ

Percent of homes with AC: **50%**

Other inputs

Run Model

Peak day cooling load shape



Peak = 4 MW

With UQ

Percent of homes with AC: **50% ± 10%**

Other inputs

Example of UQ

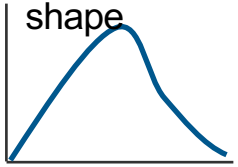
Without UQ

Percent of homes with AC: **50%**

Other inputs

Run Model

Peak day cooling load shape



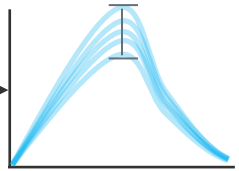
Peak = 4 MW

With UQ

Percent of homes with AC: 40%, 43%, 50%, 56%, 59%

Other inputs

Run Model



Peak = 3.7–4.2 MW

The uncertainty range is propagated through the model to determine uncertainty of outputs

“Quantities of Interest” = Key Model Outputs

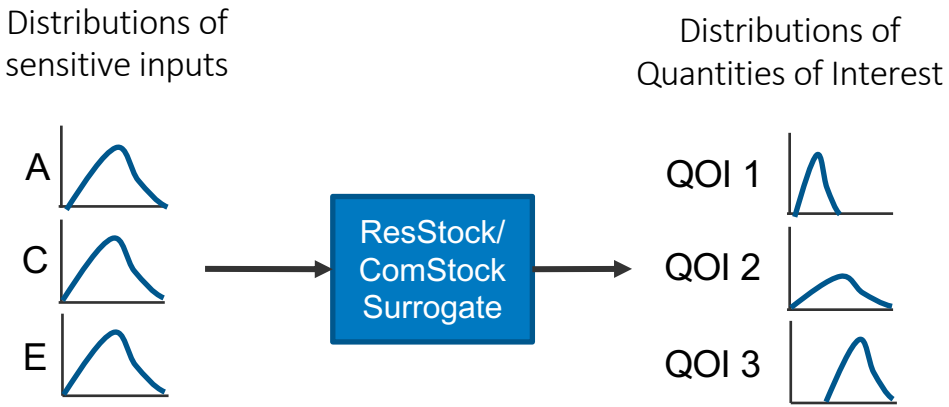
- Outputs that will contain uncertainty bounds
- Quantities to be primary focus for calibration

QOIs: by building type, region, and end use

- Annual energy use (MWh)
- Average daily minimum magnitude (MW)
  - Summer, All days
  - Winter, All days
  - Shoulder, All days
- Average daily maximum magnitude (MW)
  - Summer, All days
  - Summer, Top 10 days
  - Winter, All days
  - Winter, Top 10 days
  - Shoulder, All days
- Average daily maximum load timing (hour of day)
  - Summer, All days
  - Summer, Top 10 days
  - Winter, All days
  - Winter, Top 10 days
  - Shoulder, All days

Summary of UQ Process

1. **Sensitivity Analysis:** which model inputs matter most for each QOI
2. **Input Distributions:** uncertainty distribution for sensitive inputs
3. **Surrogate Model:** emulate ResStock / ComStock
4. **Uncertainty Propagation**: quantify uncertainty distributions of outputs



Next Steps

Next steps

- Continue procuring AMI data and commercial building end use data
- Continue residential and commercial occupancy modeling
- Complete framework for uncertainty quantification
- Complete residential sector calibration for the first region

Thank you

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Discussion

We are going to unmute all of the phone lines, so please mute yourself if you are not speaking.